Introduction to Machine Learning

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A Few Quotes

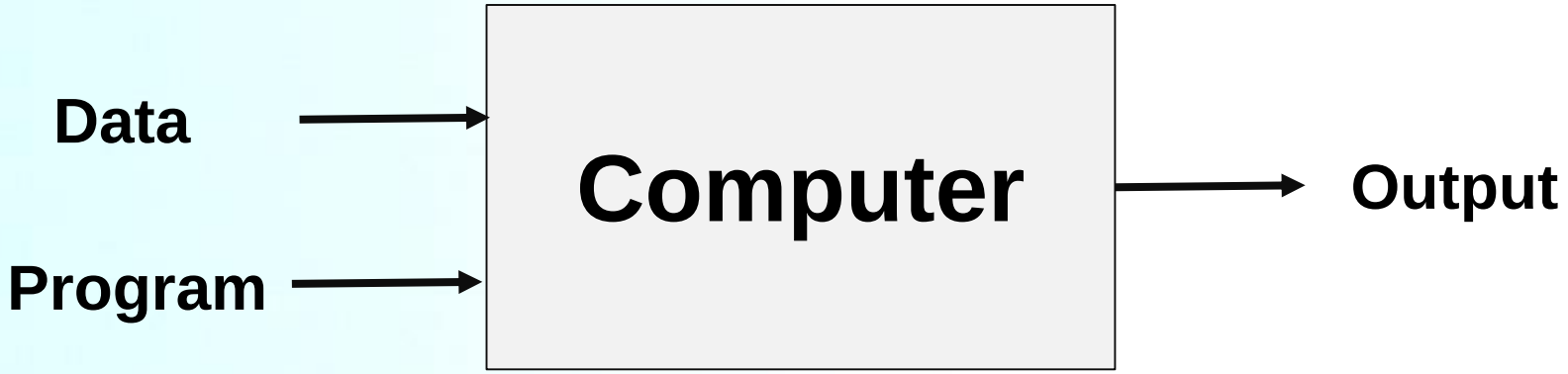
- “A breakthrough in machine learning would be worth ten Microsofts”
  - Bill Gates, Chairman, Microsoft
- “Machine learning is the next Internet”
  - Tony Tether, Director, DARPA
- “Machine learning is the hot new thing”
  - John Hennessy, President, Stanford
- “Web rankings today are mostly a matter of machine learning”
  - Prabhakar Raghavan, Dir. Research, Yahoo
- “Machine learning is going to result in a real revolution”
  - Greg Papadopoulos, Former CTO, Sun
- “Machine learning is today’s discontinuity”
  - Jerry Yang, Founder, Yahoo
- “Machine learning today is one of the hottest aspects of computer science”
  - Steve Ballmer, CEO, Microsoft

What is Machine Learning?

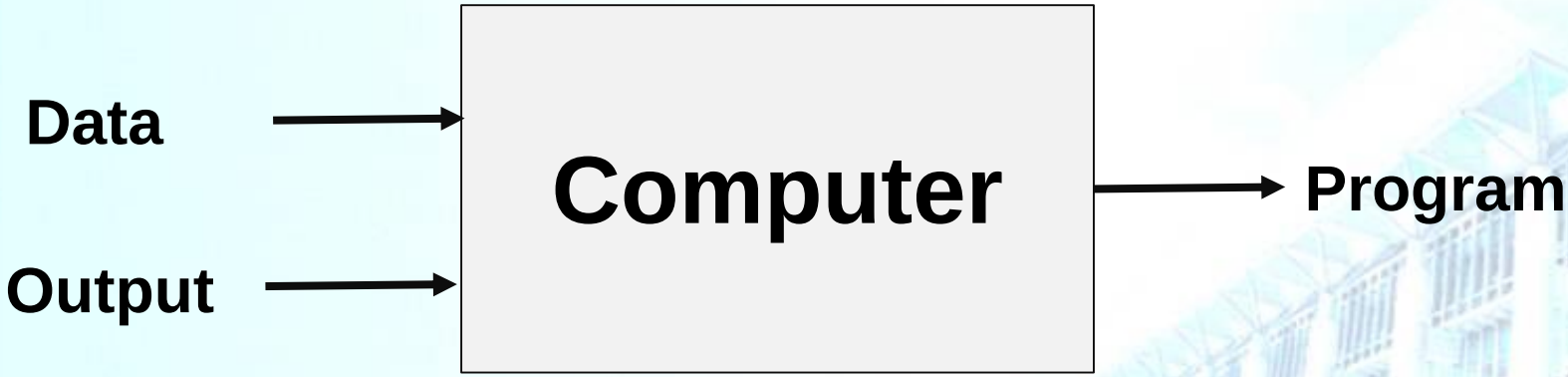
- Automating automation
- Getting computers to program themselves
- Writing software is the bottleneck
- Let the data do the work instead!

Traditional Program vs Machine Learning

- Traditional program



- Machine learning



When Do We Use Machine Learning?

- ML is used when
  - Human expertise does not exist
    - Navigating on Mars
  - Humans cannot explain their expertise
    - Walking, Speech recognition
  - Models must be customized
    - Personalized medicine
  - Models are based on huge amounts of data
    - Genomics
  - Solution changes in time
    - Routing on a computer network

More Examples of ML

- Recognition of patterns
  - Facial identities or facial expressions
  - Handwritten or spoken words
  - Medical images
- Generation of patterns
  - Generating images or motion sequences
- Recognition of anomalies
  - Unusual credit card transactions
  - Unusual patterns of sensor readings in a nuclear power plant
- Prediction
  - Future stock prices or currency exchange rates

Application Areas

- Computer vision
- Speech recognition
- Web search
- Computational biology
- Finance
- E-commerce
- Space exploration
- Robotics
- Information extraction
- Social networks
- Debugging
- …

Machine Learning

- Every machine learning algorithm has three components:
  - Representation
  - Evaluation
  - Optimization

Representation

- Decision trees
- Sets of rules / Logic programs
- Instances
- Graphical models (Bayes/Markov nets)
- Neural networks
- Support vector machines
- Model ensembles
- …

Evaluation

- Accuracy
- Precision and recall
- Squared error
- Likelihood
- Posterior probability
- Cost / Utility
- Margin
- Entropy
- K-L divergence
- …

Optimization

- Combinatorial optimization
  - Greedy search
- Convex optimization
  - Gradient descent
- Constrained optimization
  - Linear programming

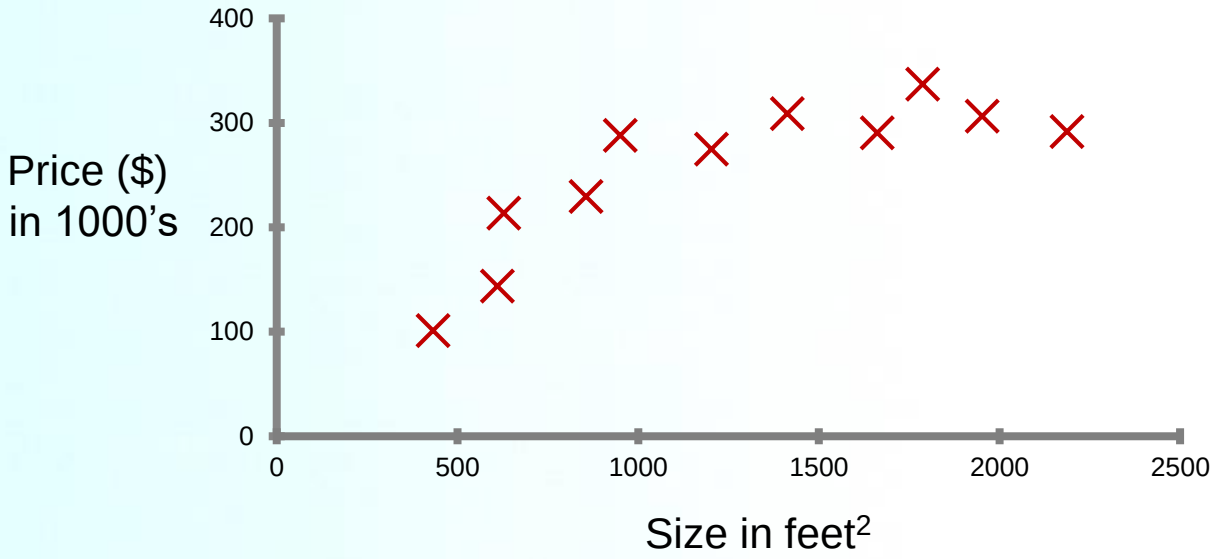
Types of Learning

- Supervised (inductive) learning
  - Given: training data + desired outputs (labels)
- Unsupervised learning
  - Given: training data (without desired outputs)
- Semi-supervised learning
  - Given: training data + a few desired outputs
- Reinforcement learning
  - Rewards from sequence of actions

Inductive Learning

- **Given** examples of a function $(x, f(x))$
  - **Predict** function $f(x_{new})$ for a new example x_{new}
    - Discrete $f(x)$: Classification
    - Continuous $f(x)$: Regression
    - $f(x)$ = Probability(x): Probability estimation

Supervised Learning: Regression



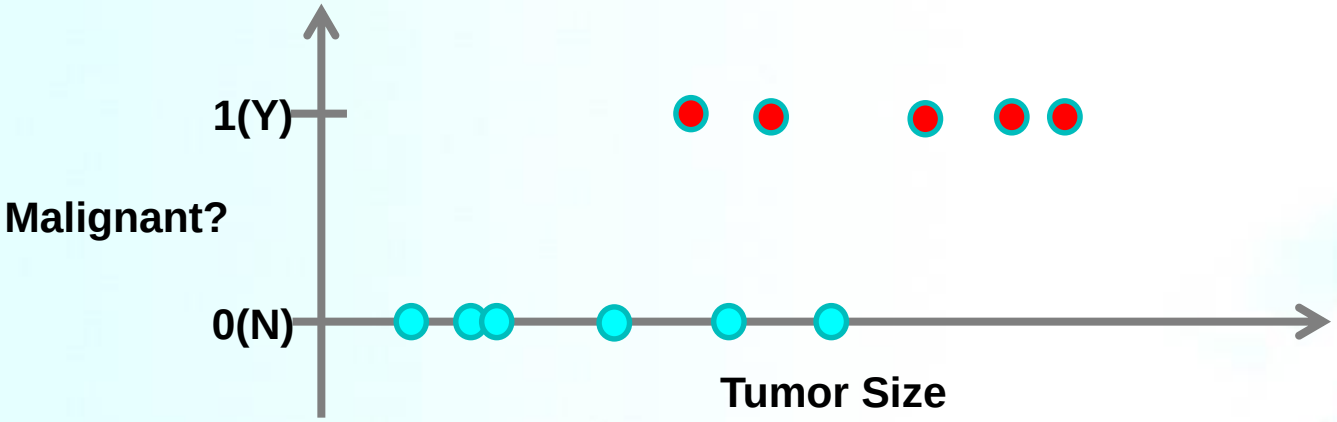
- Supervised Learning
  - "right answers" given
    - Given $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$
      - Learn a function $f(x)$ to predict y given x
      - y is real-valued ➔ regression

- Regression
  - Predict continuous valued output (price)

Supervised Learning: Classification

- Given $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$
  - Learn a function $f(x)$ to predict y given x
  - y is categorical ➔ classification

- Classification
  - Discrete valued output (0 or 1)



Supervised Learning: Classification

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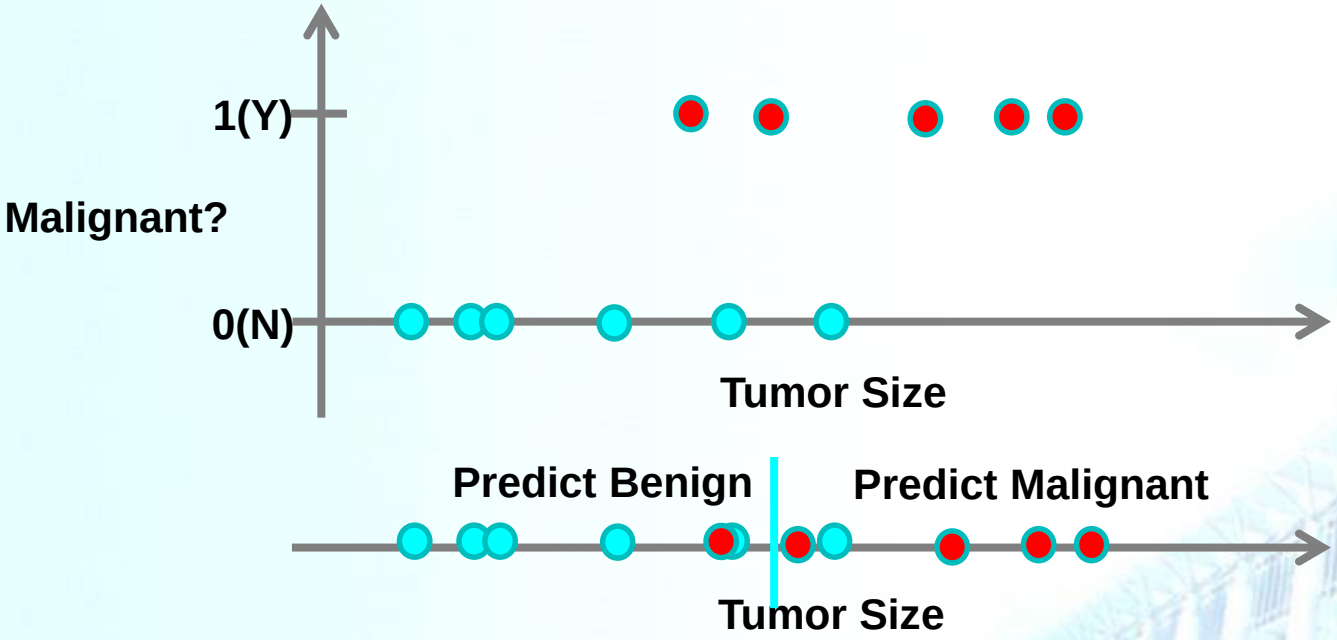
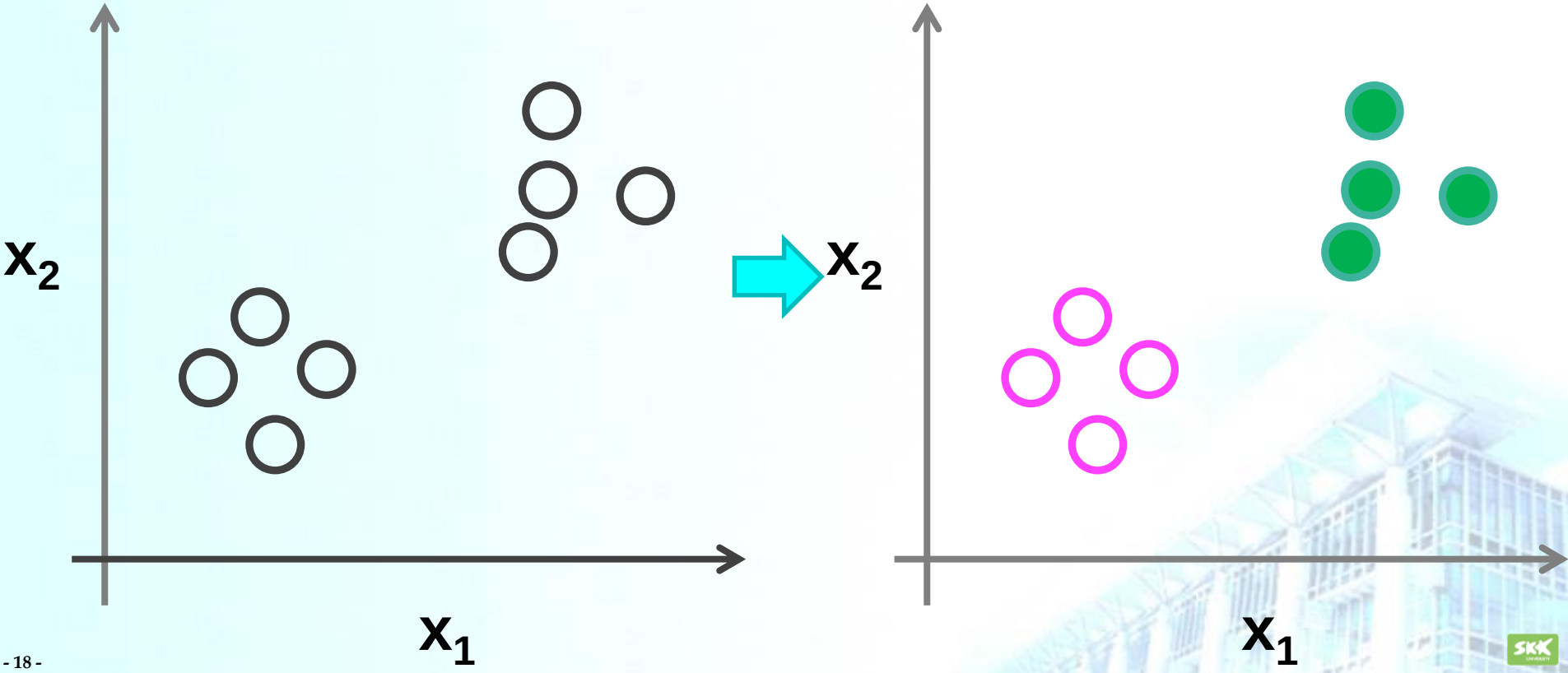


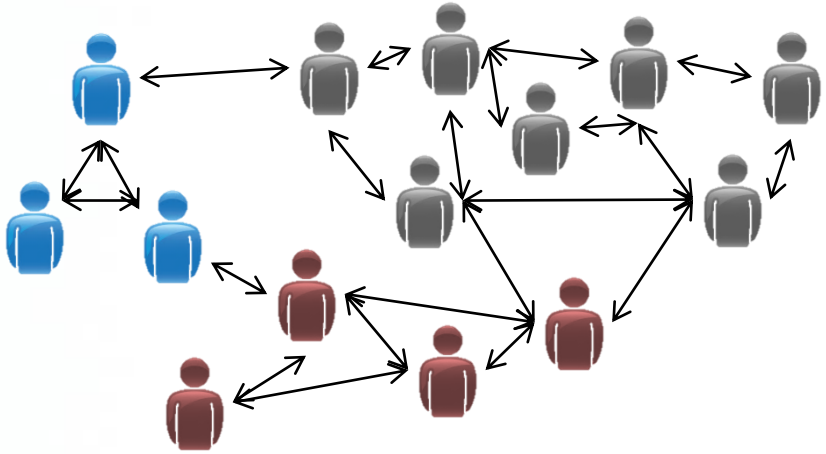
Unsupervised Learning

- Given $x_1, x_2, ..., x_n$ (without labels)
  - Output hidden structure behind the x's
    - clustering

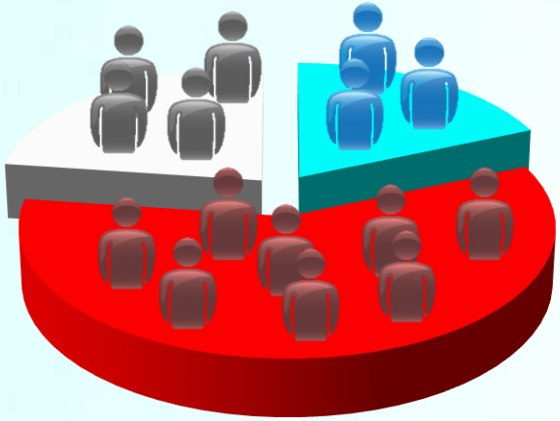


Unsupervised Learning

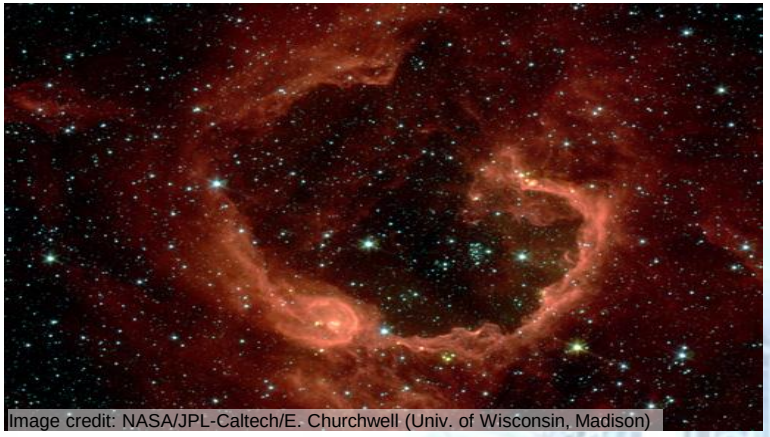
Organize computing clusters



Social network analysis



Market segmentation



Astronomical data analysis

Reinforcement Learning

- Given a sequence of states and actions with (delayed) rewards, output a policy
  - Policy is a mapping

    from states ➔ actions that tells us what to do in a given state

- Examples:
  - Credit assignment problem
  - Game playing
  - Robot in a maze
  - Balance a pole on your hand

Machine Learning Definition

- Arthur Samuel (1959)
  - Machine Learning
    - Field of study that gives computers the ability to learn
      without being explicitly programmed.

- Tom Mitchell (1998)
  - Well-posed Learning Problem:
    - A computer program is said to *learn* from experience E
      with respect to some task T and some performance measure P,
      if its performance on T, as measured by P, improves with experience E.
  - Machine Learning
    - Study of algorithms that
      - improve their performance P
      - at some task T
      - with experience E.

Machine Learning Definition

- Suppose our email program watches which emails we do or do not mark as spam, and based on that learns how to better filter spam.
  - Task T
    - Classifying emails as spam or not spam
  - Experience E
    - Watching that we label emails as spam or not spam.
  - Performance P
    - The number (or fraction) of emails correctly classified as spam/not spam.

Machine Learning Definition

- Improve on task T, wrt performance metric P, based on experience E

  - T: Playing checkers
  - P: Percentage of games won against an arbitrary opponent
  - E: Playing practice games against itself

  - T: Recognizing hand-written words
  - P: Percentage of words correctly classified
  - E: Database of human-labeled images of handwritten words

  - T: Driving on four-lane highways using vision sensors
  - P: Average distance traveled before a human-judged error
  - E: A sequence of images and steering commands recorded while observing a human driver

References

- Andrew Ng, https://www.coursera.org/learn/machine-learning
- Eric Eaton, https://www.seas.upenn.edu/~cis519
- Pedro Domingos, https://courses.cs.washington.edu/courses/cse446/14wi/